NISTIR 6242

ANNUAL CONFERENCE ON FIRE RESEARCH
Book of Abstracts
November 2-5, 1998

Kellie Ann Beall, Editor

Building and Fire Research Laboratory
Gaithersburg, Maryland 20899

United States Department of Commerce
Technology Administration
National Institute of Standards and Technology

NISTIR 6242

ANNUAL CONFERENCE ON FIRE RESEARCH
Book of Abstracts
November 2-5, 1998

Kellie Ann Beall, Editor

October, 1998
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

U.S. Department of Commerce
William M. Daley, *Secretary*
Technology Administration
Gary Bachula, *Acting Under Secretary for Technology*
National Institute of Standards and Technology
Raymond G. Kammer, *Director*

Measurements of Heat Release Rate and Vorticity Distributions in a Buoyant Diffusion Flame for the Calculation of Fire Induced Flows

J. P. Gore and X. C. Zhou
School of Mechanical Engineering,
Purdue University
West Lafayette, IN 47907-1003

Fire induced flows are of importance in a variety of fire phenomena including entrainment, pollutant formation, fire size and fire spread. A recipe pioneered by Baum and McCaffrey[1] at NIST utilizes the distributions of heat release rates and vorticity in the fire in the evaluation of the fire induced flow field. In this work, we utilize mean mixture fraction measurements and mean velocity measurements in the fire to deduce these distributions. Using these distributions in conjunction with the methodology of Ref. [1], we have calculated the flow field of a 7.1 cm natural gas fueled buoyant flame. The results are in excellent agreement with experimental data.

The methodology of Baum and McCaffrey involves separating the velocity field into irrotational and solenoidal components. The irrotational component is described by a velocity potential Φ, which is governed by $\nabla^2\Phi = Q$ and the solenoidal velocity component V is governed by $\nabla x V=\omega_p$. The source Q for the velocity potential consists of normalized heat conduction and heat release rate contributions and that for the solenoidal velocity component is the vorticity ω_p in the fire. Using conservation of energy and conservation of mixture fraction the source Q is related to the diffusion rate of mixture fraction (defined as the fraction of local mass that originates in the fuel stream) and the rate of change of specific volume with respect to mixture fraction. The vorticity in the fire is by definition the curl of the velocity field. We used measurements of mean mixture fraction obtained using sampling and gas chromatography to estimate the source term Q. We also used measurements of the velocity field obtained with particle imaging velocimetry to obtain the vorticity in the fire.

Figure 1 shows sample measurements of the velocity potential source term at three axial stations above a 7.1 cm natural gas fire. The measurements show that the source term is nonzero in an annular region where the flame sheet resides. The small negative values at intermediate radial location result from the dominance of thermal conduction away from the flame sheet in this region. The large positive values result from heat release in the flame sheet. Figure 2 shows measurements of vorticity at four axial stations above the fire. The two components of vorticity and their summation are shown. At lower elevations the derivative of radial velocity contributes to the vorticity but at higher elevations the radial derivative of the axial velocity dominates. The correlations from Ref. 1 overestimate the source at larger radii but underestimate it at shorter radii. This caused discrepancies in measurements and predictions of entrainment velocity as discussed in Ref. 2. The modified source terms based on visible flame radius used in Ref. 2 are also shown in Fig. 2 and approximate the data better except for the 1 cm location.

Figure 3 shows measurements and predictions of the two dimensional velocity field in the fire obtained using the source term distributions at many stations similar to those shown in Figs. 1 and 2. The qualitative and quantitative agreement between the measurements and predictions observed in Fig. 3 suggests that given an appropriate estimate of the source terms, the velocity field can be calculated using the NIST methodology. The flow field shows low velocities near the fuel surface and strong acceleration close to it.

References:
[1] Baum H. R. and McCaffrey B. J., *Fire Safety Science – Proceedings of the Second International Symposium*, Tokyo, Japan, 1988.
[2] Zhou, X. C., Gore J. P., and Baum H. R., *Twenty Sixth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, pp. 1453-1459 (1996).
Acknowledgement: NIST Grant number NANB6D0118 with Dr. Baum serving as Program Officer supports this work.

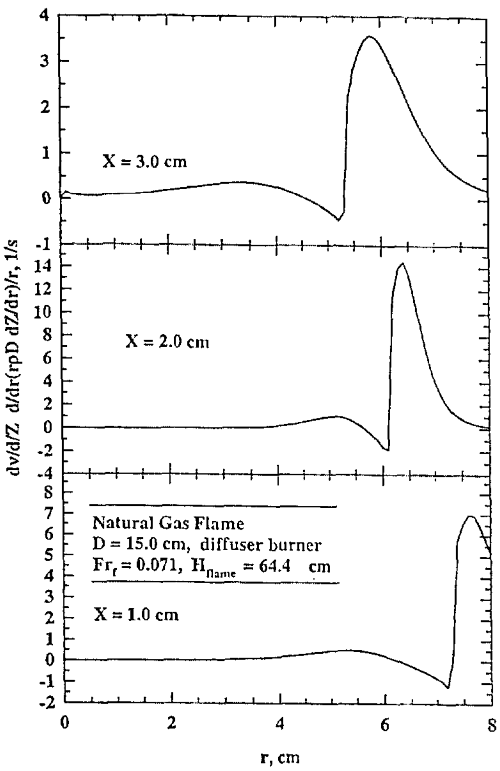

Figure 1: Source term for velocity potential deduced from mixture fraction measurements.

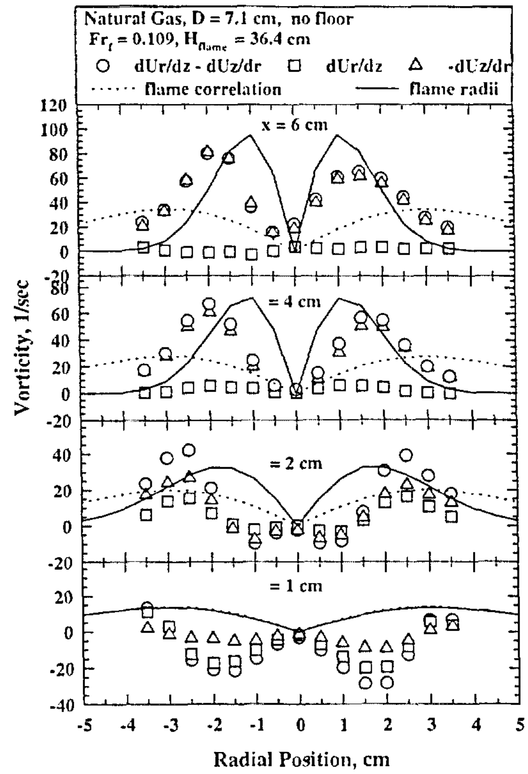

Figure 2: Vorticity deduced from velocity measurements and past correlations.

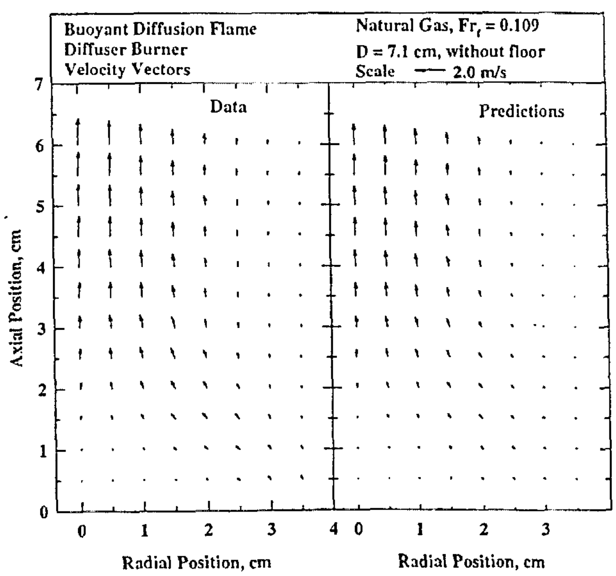

Figure 3: Measurements and predictions of two dimensional mean velocity vectors in a 7.1 cm fire.